JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
312/96.DTL-37
July 19, 1996

TO: **Sam Dallas**

FROM: **Dan Lyons** 264-214 x 31004

SUBJECT**: Walkin Simulations with Fixed ∆V Sizes.**

INTRODUCTION:

Memo 312/96.DTL-36, "**Fixed ∆V Sizes for Aerobraking"** of July 17, 1996 by Dan Lyons defined a set of Fixed ∆V sizes for the aerobraking phase. This memo will examine some typical Walkin scenarios using these maneuver sizes and the VPOHOP trajectory simulation tool. Previous VPOHOP simulations have always used variable Walkin maneuver sizes that were chosen to reach the start of the Main Phase after maneuver AB-4, which was executed on Orbit#16. (Mar Orbit Insertion, MOI, begins Orbit#1.)

The maneuver size that is selected in these simulations is based on the current atmospheric density (which will be reconstructed in actual operations by the Navigation team), and the "Critical Scale Height" of the planned maneuver. The "Critical Scale Height" is described in memo 312/96.DTL-28, "**Critical Scale Height During Walkin"** March 22, 1996 by Dan Lyons and has been discussed at subsequent Mission Design Team Meetings (visit http://caseymac/mgs/ to view the MDT presentations). Basically, the Critical Scale Height is the scale height that would be required to reach the critical density (143 kg/km^3) from the current density using the planned maneuver. As long as the Critical Scale Height is less than the minimum realistic scale height (6 km), then the maneuver is safe. The problem is that as the Critical Scale Height that defines the maneuver threshold where the next smaller maneuver is selected from the predetermined list of available ∆V's is reduced, the number of Walkin maneuvers is increased. Earlier examples, using purely exponential models and various triggering thresholds and maneuver sizes, have resulted in Walkin Phases requiring as many as 8 maneuvers. The the smaller (3 km) Critical Scale Height threshold example in this memo requires 7 maneuvers.

Since the heating rates during the Main Phase are highly dependent on the duration of the Walkin Phase, and since the number of Walkin maneuvers is expected to be greater than the 4 maneuvers used for preliminary planning, the number of orbits between Walkin maneuvers has been reduced from 3 or 4 to 2 in order to fit a greater number of Walkin maneuvers into the time allocated for Walkin. Since the density following AB-1 is almost guaranteed to be very small, AB-2 will be performed on the very next apoapsis, unless observations of the conditions at Periapsis cause the operations team to delay AB-2 to a later orbit. Note that the density following AB-1 in these simulations is large enough to make a difference in the size of the AB-2 maneuver for the two Critical Scale Height thresholds that are examined.

Plots of the trajectories will be discussed later in this memo.

DISCUSSION:

All trajectories begin at the first apoapsis following MOI using the orbital elements from the Mars Global Surveyor Trajectory Characteristics Document for the Open of the Launch period. Two different Critical Scale Height Thresholds are considered: 4 km and 3 km. The Walkin Maneuvers occur every other orbit. Table 1 summarizes the results. Column 1 indicates the Aerobraking Maneuver number and the Orbit # of the maneuver. (All maneuvers in VPOHOP occur exactly at Apoapsis with the ΔV aligned with the velocity vector.) Two or three choices for the maneuver are given in the cells of the table. The numbers in Boldface indicate the maneuver that was used. The other maneuver size is usually the next larger maneuver, which is included to illustrate that for most maneuvers it might be reasonable to choose the next larger maneuver in order to speed up the Walkin process. Each entry includes the maneuver size (m/s), the associated Critical Scale Height (km) based on the density from the simulation at the previous (most recent) periapsis, and (In Parentheses) the scale height (km) required to “overshoot” the Main Phase density (70 kg/km^3). This “Overshoot” Scale Height is most useful for assuring that the last Walkin maneuver does not change the periapsis altitude enough to overshoot the desired main phase density. The Critical Scale Height assures that the density following the maneuver will be less than the critical density, but says nothing about what the actual density will be.

Table 1: Simulation Results for 3 & 4 km Critical Scale Height Thresholds

	4 km Hs*	**3 km Hs***
AB-2 (Apo#6)	0.6 m/s, 2.8 km (3.2 km) **0.8 m/s, 3.7 km (4.3 km)**	**0.6 m/s, 2.8 km (3.2 km)** 0.8 m/s, 3.7 km (4.3 km)
AB-3 (Apo#8)	**0.4 m/s, 2.9 km, (3.6 km)** 0.6 m/s, 4.4 km, (5.4 km)	**0.4 m/s, 2.5 km, (3.1 km)** 0.6 m/s, 3.8 km, (4.6 km)
AB-4 (Apo#10)	**0.2 m/s, 2.3 km, (3.4 km)** 0.4 m/s, 4.6 km, (6.7 km)	**0.2 m/s, 1.8 km, (2.3 km)** 0.4 m/s, 3.5 km, (4.7 km)
AB-5 (Apo#12)	***0.1 m/s, 1.7 km, (3.2 km)*** **0.2 m/s, 3.3 km, (6.3 km)** 0.4 m/s, 6.7 km, (12.6 km)	**0.2 m/s, 2.4 km, (3.6 km)** 0.4 m/s, 4.9 km, (7.3 km)
AB-6 (Apo#14)	***0.1 m/s, 2.1 km, (5.5 km)***	**0.1 m/s, 1.7 km, (3.4 km)** 0.2 m/s, 3.5 km, (6.9 km)
AB-7 (Apo#16)		***.05 m/s, 1.1 km, (2.8 km)*** **0.1 m/s, 2.1 km, (5.6 km)** 0.2 m/s, 4.2 km, (11.2 km)

For the second column (4 km Critical Scale Height threshold), blindly using 4 km as the threshold for all of the Walkin Phase would mean that AB-5 would be the last Walkin maneuver, since the density is greater than 60 kg/km^3 (within a minimum maneuver of the maximum average Main Phase density). The numbers in *Italics* indicate a more cautious option for the final Walkin maneuver. Since the "overshoot" scale height for AB-5 is greater than 6 km (but only by 0.3 km), there was a small chance that the planned maneuver could overshoot the desired density. Since the project would like to characterize the variability of the atmosphere before fully committing the spacecraft, a realistic Walkin would use the smaller (0.1 m/s) size for AB-5, and might even delay AB-6 by several orbits. Since significant drag would be shrinking the apoapsis by this point, delaying the last Walkin maneuver does not have much effect on the heating rates required to reach the 2 pm Mapping Orbit. Even the more conservative "italicized" Walkin reaches the Main Phase two orbits earlier than the "Baseline" presented at the CDR, and maintains the desired heating rate margins.

Using a 3 km Critical Scale Height (column 3 of Table 1) results in a greater number of Walkin maneuvers, as expected. Using only a 3 km Critical Scale Height threshold increases the number of Walkin maneuvers to 7, an increase of 2 maneuvers. Performing the Walkin maneuvers every other orbit results in a Walkin phase that is exactly the same length as the "Baseline", which assumed 4 Walkin maneuvers placed every 4th orbit. An AB-7 of 0.1 m/s results in a density of 65 kg/km^3 at the next periapsis, and Walkin is "Complete". The total ΔV for Walkin is the same as for the previous case. Because the trajectory evolves differently, the longitude at the descending node is different, and the gravitational perturbations on the periapsis altitude are different. While in the previous cases with a 4 km Critical Scale Height, the density at periapsis for the next several orbits remains relatively constant (64 kg/km^3 after AB-5, 70 kg/km^3 max.), the density with a 3 km Critical Scale Height undergoes a larger change (66 kg/km^3 after AB-7, 77 kg/km^3 max.) due to the perturbations acting on the orbit. The prudent thing to do would be to use the next smaller maneuver to end the Walkin phase (even though the density is only 56 kg/km^3), and allow the predicted perturbations to finish the job. Thus the second "half-sized" last maneuver was not needed in this example (3 km Critical Scale Height).

NOTE: When deciding what maneuver size to use for the last Walkin Maneuver, it is a necessary to look several orbits into the future in order to see what the perturbations are doing to the periapsis altitude. This is especially true if the MOI orbit period is slightly larger than 48 hours, such that the orbit is in a 2:1 resonance with the planet rotation.

Not all of the density fluctuation in the simulation could be correlated with the altitude of periapsis, so there may be a longitude dependent density variation in MarsGRAM which is contributing to the density fluctuations.

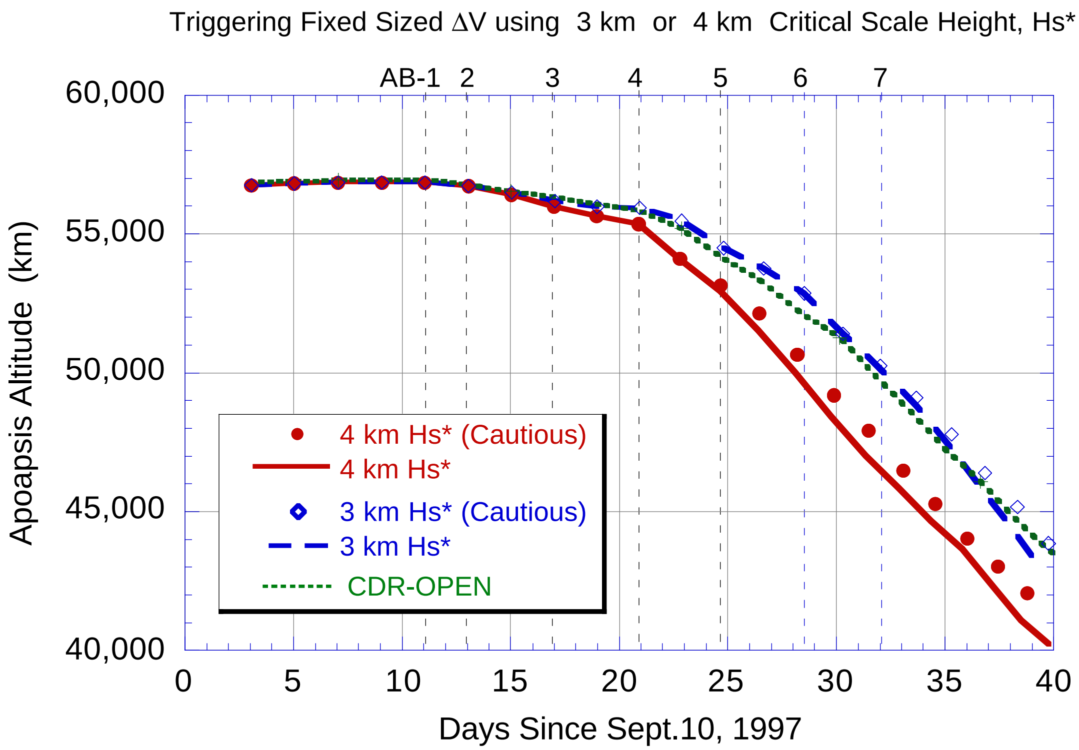

Figure 1: Apoapsis Altitudes during Walkin

Figure 1 shows the evolution of the apoapsis altitude during the Walkin phase for the 4 new trajectories and for the Baseline for the Open of the launch period from the Mission System Critical Design Review (CDR). Using an apoapsis of 50,000 km as the “start of Main Phase”, the larger (more aggressive) 4 km Critical Scale Height threshold for maneuver selection reduces the Walkin phase by 4 Days, which increases the Main Phase by 4 Days. Since the Atmospheric Blooming Margin increases by about 4% per extra day of Main Phase, entering the Main Phase 4 Days earlier would add about 16% Margin to the Atmospheric Blooming Margin. Although the difference between the 3 km and 4 km Critical Scale Height maneuver selection thresholds is much larger than the difference between the “Cautious Last Walkin Maneuver”, which cuts the last Walkin maneuver into two half-sized maneuvers, and the “use the same Critical Scale Height all the way to Main Phase” approach, there is still about a difference of One Day between the Cautious and Nominal approaches. Although a One Day difference is not significant, the operations team must be careful not to let the total number of days to slip much behind the Baseline Plan.

Figure 2 shows the Periapsis Altitudes during Walkin. The first 4 orbits after MOI are at an altitude of 313 km. Periapsis is lowered to the upper fringes of the atmosphere with the first walkin maneuver, AB-1, which is targeted to a periapsis altitude of 150 km. (Note that the Baseline for the CDR was targeted to 135 km.) By the start of the Main Phase, all of these example trajectories end up at 110 km, because they all use MarsGRAM as the “truth model”. During the actual Walkin, the maneuvers will be selected based on the actual densities encountered at the time.

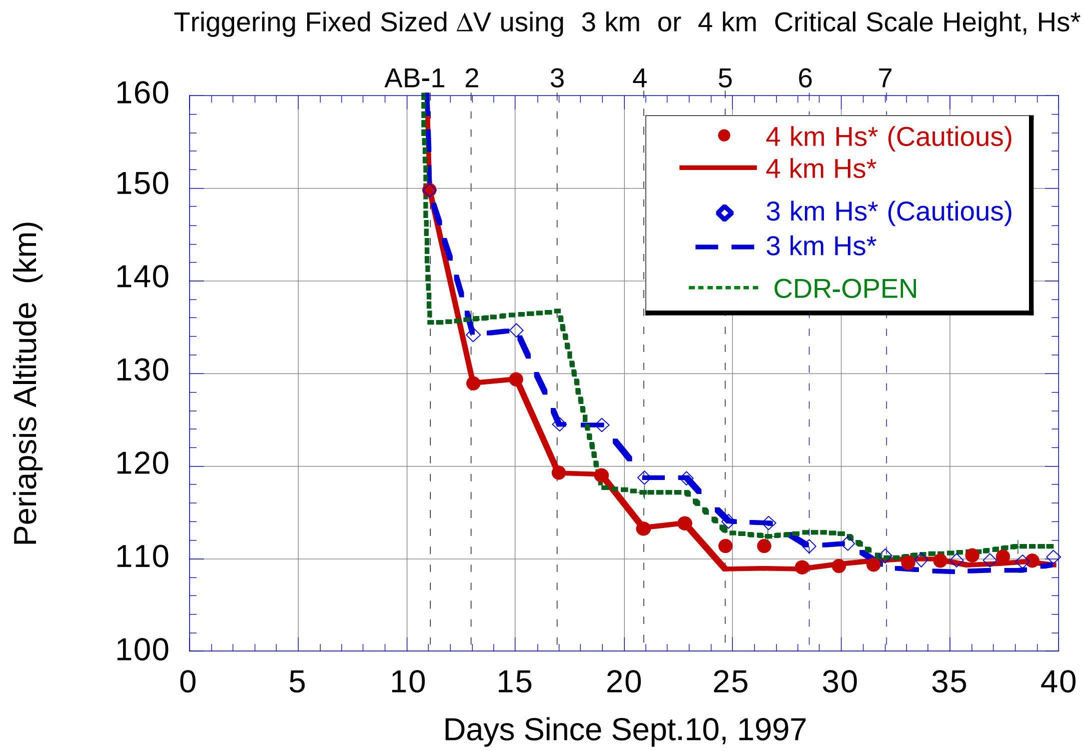

Figure 2: Periapsis Altitudes during Walkin

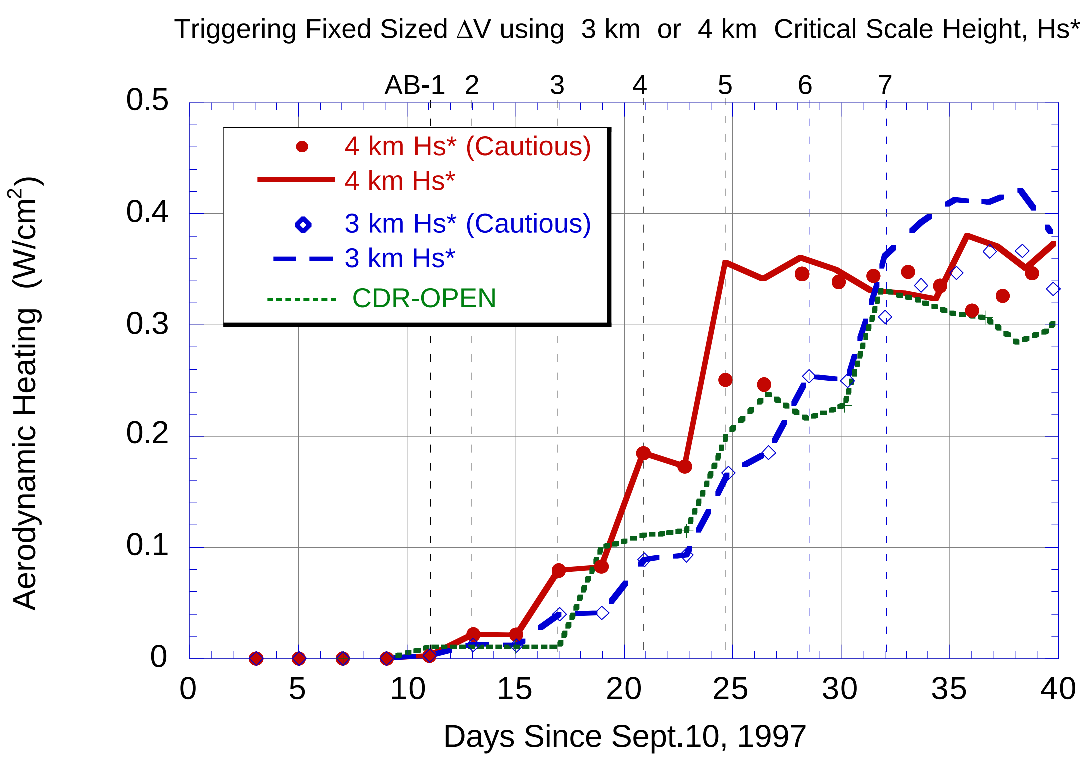

Figure 3: Aerodynamic Heating during Walkin

Figure 3 shows the Aerodynamic Heating Rate ("Qdot") at periapsis during Walkin. The "Cautious" and "Nominal" for the specified Critical Scale Height maneuver selection threshold are identical up to the last maneuver. The last maneuver is split into two "half-sized" maneuvers for the "Cautious" approach. Note that the trajectory evolves differently if two "half-sized" maneuvers are used, as seen in the differences between the Heating rates for the 4 km Critical Scale Height example, because the longitudes are slightly different because the period reduction was larger for the Nominal case for the two orbits between the first and second "half-sized" maneuvers with the more cautious approach. (For the 3 km Critical Scale Height case, the second "half-sized" maneuver was never executed because the perturbations on the trajectory were large enough lower periapsis across the "threshold" that defined the start of the Main Phase.) Although the apoapsis plot shows that the Baseline for the CDR is very similar to the 3 km Critical Scale Height maneuver selection threshold trajectories, the density plots show a significant difference after Day 35 (since Sept.10) because the gravitational perturbations are different because the longitude at periapsis is different.

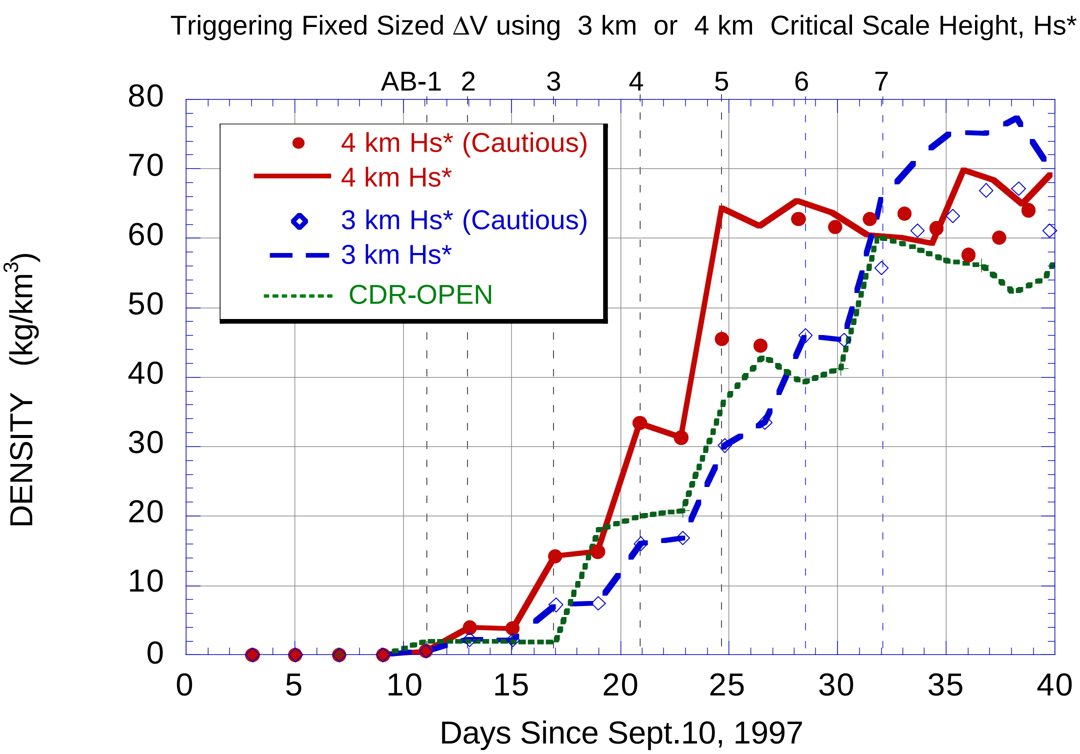

Figure 4: Density at Periapsis during Walkin

Figure 5 shows the Density plotted versus Periapsis Altitude. If the atmospheric density model was only a function of altitude, all of the data points would fall on a line. The fact that there are a range of densities at a given altitude are due to the longitudinal dependency in the MarsGRAM atmospheric model. It is not known how well the atmospheric model reproduces the longitudinal effects, especially at the higher altitudes associated with aerobraking.

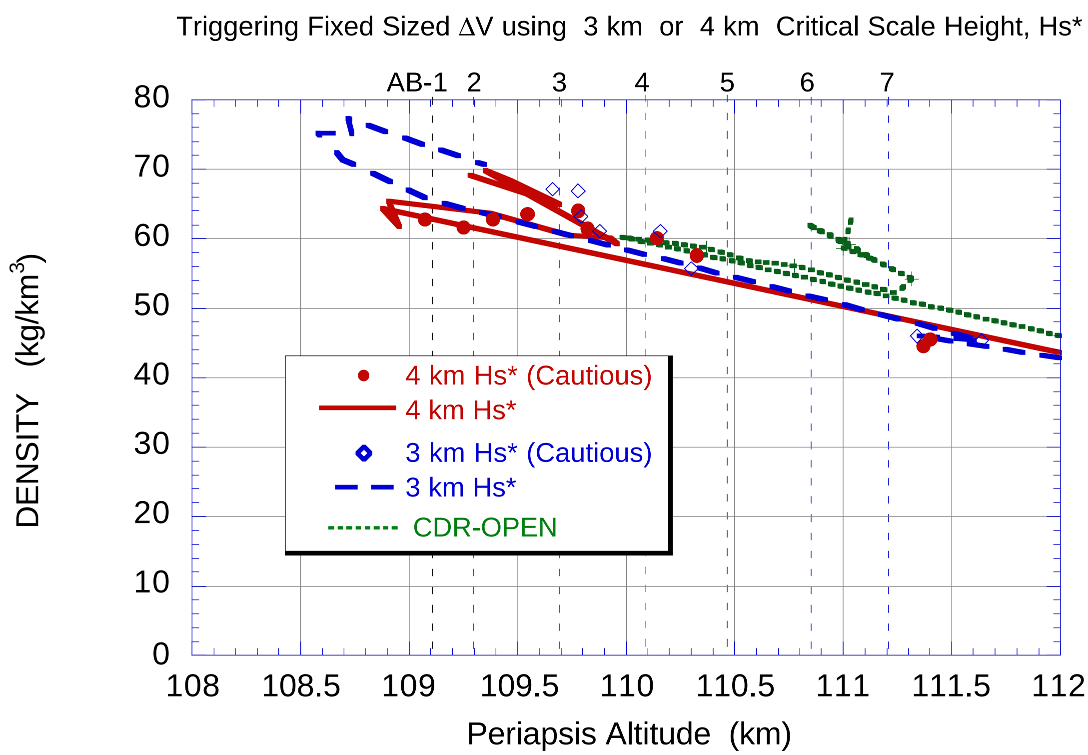

Figure 5: Density versus Periapsis Altitude during Walkin

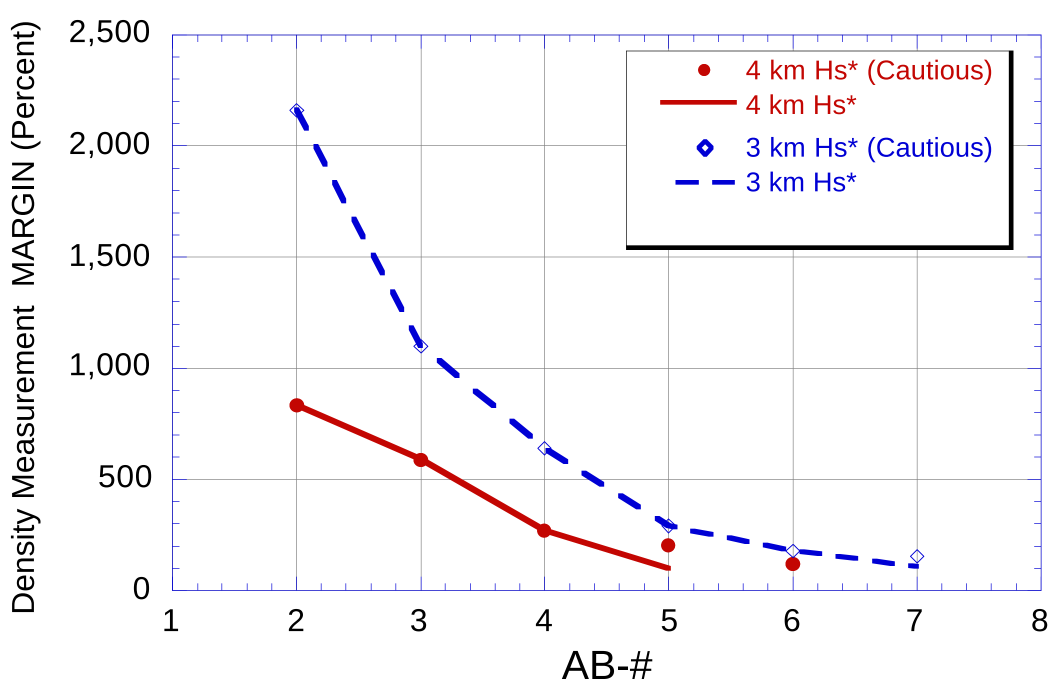

Figure 6: Margin for Density Measurement Error during Walkin

One of the concerns associated with Walkin is the fact that there will be measurement uncertainties associated with the reconstruction of the density at periapsis. Since this measurement is used to select the size of the next maneuver, it is important to know how much density measurement error can be tolerated before this “Critical Scale Height” maneuver selection strategy would put the spacecraft in danger. Figure 6 shows the Margin on the density measurement for each of the maneuvers selected in the 4 new trajectories. Assuming that the minimum realistic scale height is 6 km, the “measured density” from the simulation is subtracted from the density which is associated with a Critical Scale Height of 6 km and the result is divided by the “measured density” and expressed as a percent. This Margin is never less than 100% for the example maneuvers shown in this memo. Although the margin for density measurement error decreases as the periapsis approaches the desired value for the Main Phase, the measurement accuracy as a percentage of the actual value is expected to increase, because the “signal to noise” will increase as the drag increases. Although using the larger Critical Scale Height maneuver selection means that there is less margin for density measurement error, the density measurement Margins are very large - even for the 4 km Critical Scale Height threshold. Therefore it is perfectly safe to use the 4 km Critical Scale Height maneuver selection threshold, which shortens the duration of the Walkin phase and increases the Atmospheric Blooming Margins available for the Main Phase.

CONCLUSIONS:

It is possible to design a reasonable Walkin phase using the Fixed Maneuver Sizes and the Critical Walkin threshold to pick the maneuver size. An “overshoot” scale height is useful for becoming more conservative for the last Walkin Maneuver. In general, the “Last” Walkin maneuver based on the “Critical Scale Height Threshold” will be split into two “half-sized” maneuvers. It is necessary to perform the Walkin Maneuvers every other orbit in order to complete Walkin in the allocated time to avoid increasing the average heating rate during the Main Phase. It is also desirable to predict the trajectory several orbits into the future to account for gravitational perturbations on the periapsis altitude. Although these gravitational perturbations produce density changes that are much smaller than that which can be accommodated by the “atmospheric blooming” margins, we do not know exactly how much random atmospheric fluctuation must be accommodated by the same margins. Six or seven Walkin maneuvers are highly likely.

cc:

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